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STRENGTH OF BOLTED WOOD JOINTS WITH VARIOUS RATIOS OF MEMBER TH--ETC(U)

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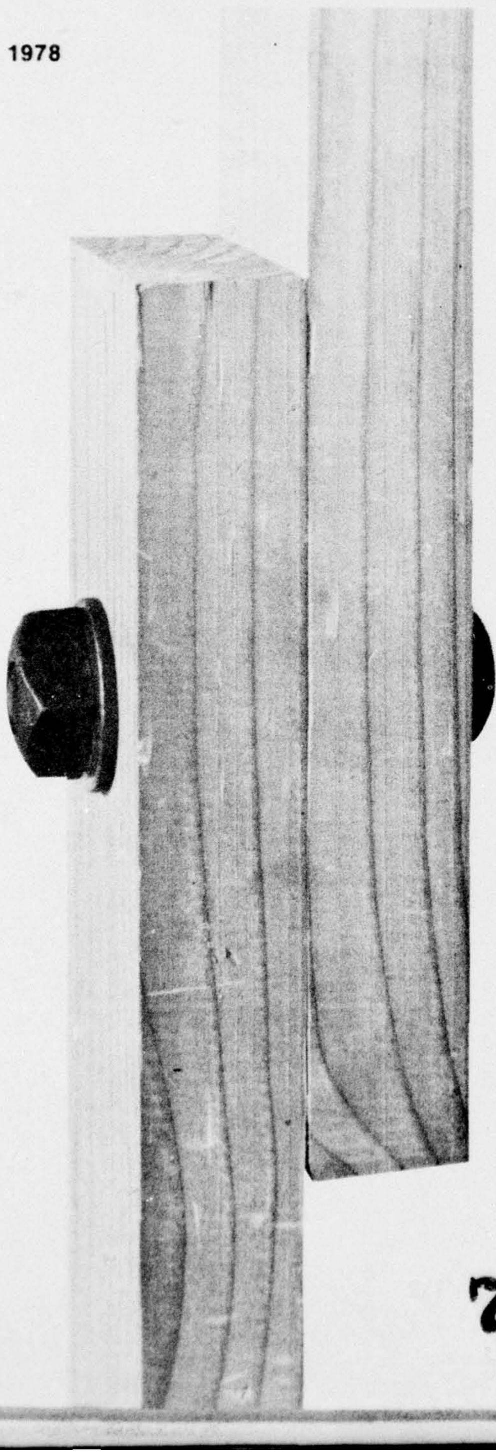

RESEARCH PAPER FPL 314
FOREST PRODUCTS LABORATORY
FOREST SERVICE
US DEPARTMENT OF AGRICULTURE
MADISON, WISCONSIN 53705

ABSTRACT

Procedures have been recommended—such as in the National Design Specification—for design of bolted joints in wood members where the side members are thicker or thinner than half the main member thickness. However, these recommendations have had no experimental verification up to now. The same is true for joints with other than three members. This study experimentally verified present rules for handling three-member and multiple-member joints, but found that present rules for two-member joints were inadequate.

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U.S. Forest Products Laboratory.

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(6) STRENGTH OF BOLTED WOOD JOINTS WITH VARIOUS RATIOS OF MEMBER THICKNESSES.

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U.S. Department of Agriculture

(11) 1978 (12) 11 p.

INTRODUCTION

Basic data for bolted joints in wood have historically been determined on three-member joints where the side member thickness is one-half the thickness of the main member. Data on strength of bolted joints reported by Trayer[2] have formed the basis for design loads for such joints as presented by NDS.[3] However, in actual practice bolted joints are not always made with the member thicknesses in a ratio of two to one. Recommendations have been formulated in NDS[3] for determining the design load on joints where the side members are thicker or thinner than half the main member, but no experimental data or theory presently exist to substantiate these rules.

In practice, bolted joints may have only two members or more than three members. Rules for determining the design loads for these joints have also been formulated in NDS[3] without experimental verification. In some cases, these rules are even contradictory.

Thus this study was initiated to determine the effect on bolted joint strength when the side members are thicker or thinner than half the main member thickness. Joints are also considered which have other than three members.

EXPERIMENTAL PROCEURE

Specimens

Several types of joints, member thicknesses, and bolt diameters were used in this study (table 1, fig. 1). All joints were loaded parallel to the grain. Six replications of each combination of variables were evaluated. All members were 5 inches wide by 18 inches long.

All members were Douglas-fir cut from large timbers (nominal 6 by 8 in.; 24-ft long) which had been stored in an open shed for several years. Approximately eight such timbers were used to provide all the needed joint members. In three-member joints, side members were from the same timber; other pieces were distributed between the various groups as evenly as possible. Knots and other growth characteristics were eliminated from the area of the bolt holes. The average moisture content of the material was about 10 percent.

Bolt holes—located 6 inches from the end of the joint member and centered between the edges—were 1/32-inch larger than the bolt diameter. In an effort to get smooth holes, drilling was done with a double spur bit. Low-carbon steel machine bolts were used with round steel washers under both the head and nut, and joints were made finger tight.

(9) Forest Service research papers

1/ Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

2/ Trayer, George W. 1932. The Bearing Strength of Wood Under Bolts. U.S. Dept. Agric. Tech. Bull. No. 332.

3/ National Forest Products Association. 1973. National Design Specification for Stress-Grade Lumber and Its Fastenings.

Table 1.—Average[1] joint properties and compression parallel to grain properties

Type of joint	Main member thickness	Side member thickness	Bolt diameter	Moisture content	Specific gravity[2]	Joint properties: Proportional limit load	Joint properties: Initial slope[3]	Compression parallel to grain properties: Maximum stress	Compression parallel to grain properties: Proportional limit stress	Compression parallel to grain properties: Modulus of elasticity
	In.	In.	In.	Pct		Lb	Lb/in	$Lb/in.^2$	$Lb/in.^2$	$1,000\ lb/in.^2$
Three-member	1-1/2	3/4	1/2	11.4	0.46	1,930	37,210	7,580	4,760	2,230
	1-1/2	3/4	3/4	11.5	.42	2,060	39,190	6,730	4,500	1,950
	1-1/2	1-1/2	1/2	11.4	.46	1,980	55,380	6,760	4,160	1,820
	1-1/2	1-1/2	3/4	11.5	.42	3,420	83,980	6,650	4,210	1,940
	2	1/2	3/8	10.5	.44	1,030	46,840	7,740	4,110	2,040
	2	1/2	1/2	9.8	.42	1,700	57,880	7,780	4,910	2,030
	2	1/2	3/4	9.2	.43	2,200	47,060	7,890	4,710	1,920
	2	1	3/8	10.6	.39	1,130	43,340	6,920	4,260	1,640
	2	1	1/2	9.9	.42	1,960	70,360	7,720	5,100	2,070
	2	1	3/4	8.9	.42	3,010	102,520	7,310	4,170	1,740
	2	1-1/2	3/8	9.5	.44	1,160	44,460	8,130	5,170	2,260
	2	1-1/2	1/2	9.4	.43	2,160	84,420	7,980	4,610	2,060
	2	1-1/2	3/4	8.6	.42	3,900	145,240	7,340	3,580	1,930
	2	2	3/8	10.1	.42	1,260	47,520	6,850	4,520	1,760
	2	2	1/2	10.2	.43	2,160	81,940	7,320	4,640	1,820
	2	2	3/4	9.4	.41	4,120	95,520	7,020	4,040	1,770
	2	2-1/2	3/8	10.6	.40	1,320	47,000	6,680	4,330	1,770
	2	2-1/2	1/2	10.3	.43	2,270	86,760	7,810	4,110	2,060
	2	2-1/2	3/4	9.5	.43	4,050	149,080	7,320	3,880	1,890
	2	3	3/8	10.5	.47	1,600	57,580	8,680	5,160	2,330
	2	3	1/2	10.1	.48	1,960	73,440	8,530	4,900	2,370
	2	3	3/4	8.9	.49	4,660	179,620	8,990	5,120	2,490
	3	3/4	1/2	11.3	0.47	1,440	41,980	7,830	4,630	2,210
	3	3/4	3/4	11.3	.44	3,180	46,850	7,200	4,300	1,920
	3	1-1/2	1/2	11.2	.46	2,320	49,860	7,360	4,560	2,180
	3	1-1/2	3/4	11.5	.42	4,220	92,120	6,450	4,600	1,960
	3	3	1/2	11.4	.46	2,140	40,030	7,260	4,240	2,150
	3	3	3/4	11.6	.42	3,980	87,080	6,360	4,450	1,910
Two-member	3	1-1/2	1/2	11.4	.47	960	14,470	7,460	4,760	2,200
	3	1-1/2	3/4	11.4	.43	1,770	22,750	6,700	4,020	1,840
	1-1/2	1-1/2	1/2	11.4	.46	840	13,580	7,110	4,100	2,150
	1-1/2	1-1/2	3/4	11.5	.41	1,170	16,770	6,610	3,980	1,860
Four-member	All members 2 inches		3/8	10.3	.41	2,500	78,690	6,990	4,460	1,860
	.........do.........		1/2	10.0	.44	3,640	98,670	7,550	4,630	1,950
	.........do.........		3/4	9.6	.44	5,980	146,620	7,640	4,430	2,000

[1] All values are the average of six specimens.
[2] Based on volume at time of test and ovendry weight.
[3] Slope of the load-deformation curve up to the proportional limit.

Method of Testing

The experimental arrangements for two-, three-, and four-member joints are shown in figures 2, 3, and 4. All joints were loaded in compression following ASTM[4] procedures where applicable. Linear variable differential transformers (LVDT's) were used to measure relative movement between joint members. This movement was plotted versus load by an x-y recorder. For the four-member joints, a separate plot was made for each shear plane; for the three-member joints, the two deformations were averaged. A rate of motion of the movable crosshead of 0.035 inch per minute was used with all joint types. Loading was stopped after a total joint deformation of 0.60 inch.

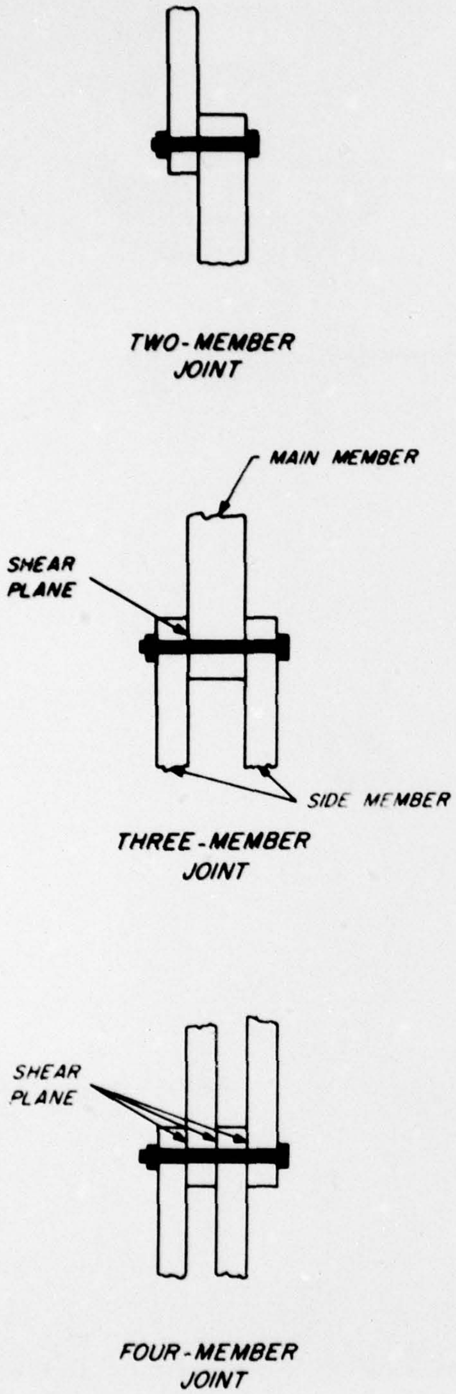

Figure 1.—Two-, three-, and four-member joints with illustration of shear planes.
(M 144 963)

After evaluation of the bolted joint, a compression-parallel-to-the-grain specimen measuring 1 inch by 1 inch was obtained from each joint. This specimen was obtained from one of the side members whenever possible, in an undamaged area near the bolt hole. Compression specimens were tested following ASTM[5] procedures and were also used to obtain specific gravity and moisture content.

RESULTS AND DISCUSSION

Average properties are given in table 1 for the joints and the small, clear specimens from the joints tested for compression parallel to the grain. A typical load-deformation curve for a three-member joint is shown in figure 5.

Values of moisture content and specific gravity (table 1) indicate a fairly uniform matching of material between the different joint types. Properties in compression parallel to grain were more variable but still indicate fairly uniform matching.

Design loads for bolted joints are based on ultimate crushing strength in compression parallel to the grain. Values of this property (table 1) appeared to be uniform enough so that no correction in the joint properties was needed before comparing the various joint types.

Ratio of Side Member to Center Member Thickness

NDS[3] tabulates loads for three-member joints where each side member is one-half the thickness of the main member. Certain design recommendations are then provided for handling other joint geometries. Procedures presently recommended by NDS[3] for design of bolted joints where side members are thicker or thinner than half the main member are as follows:

4/ American Society for Testing and Materials. Standard Methods of Testing Metal Fasteners in Wood. D1761-74. Philadelphia, Pa.

5/ American Society for Testing and Materials. Standard Methods of Testing Small Clear Specimens of Timber. D 143-52 (reapproved 1972). Philadelphia, Pa.

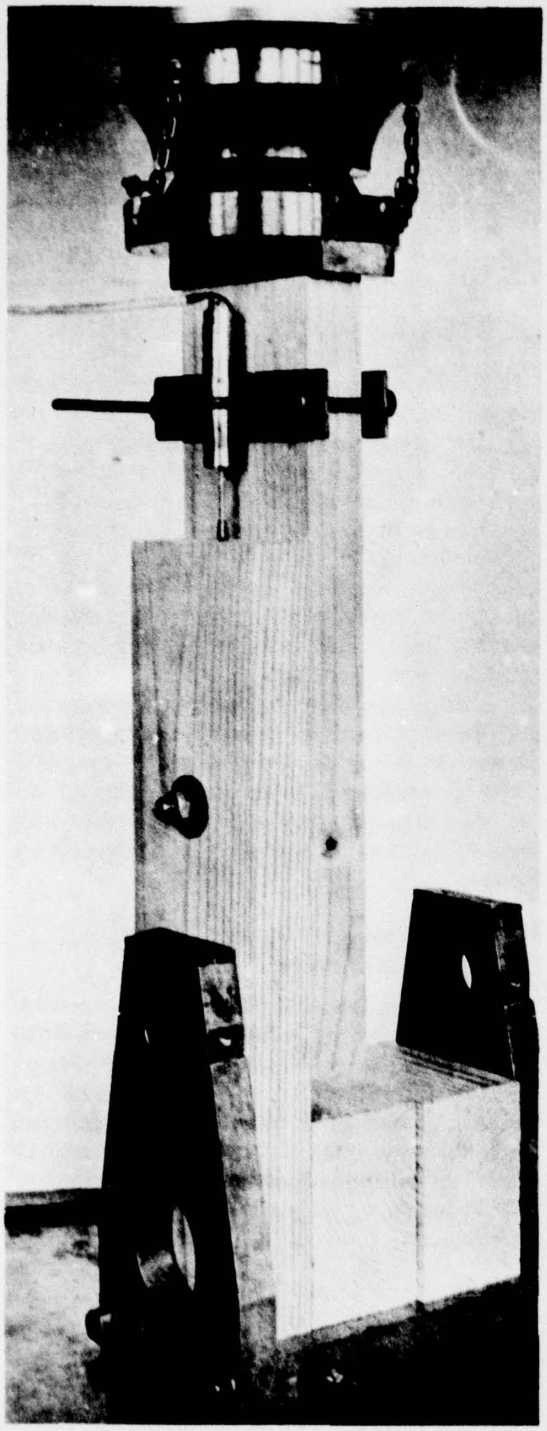

Figure 2.—Testing of two-member joints, showing placement of transducer.
(M 143 714)

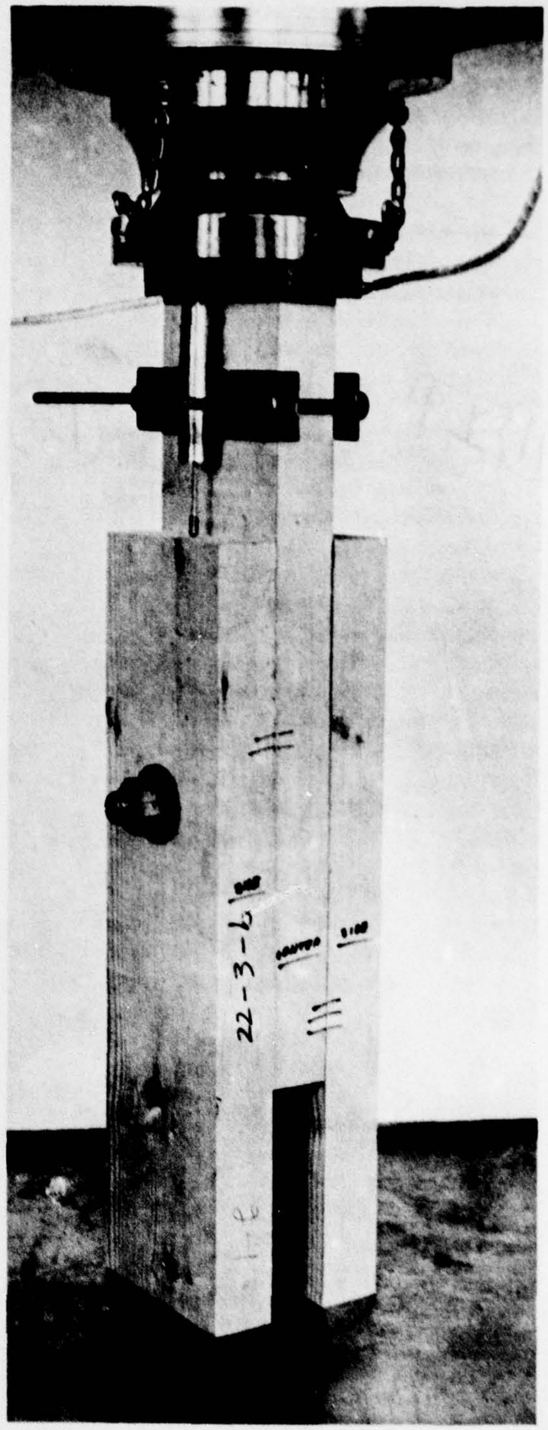

Figure 3.—Testing arrangement with three-member joints.
(M 143 715)

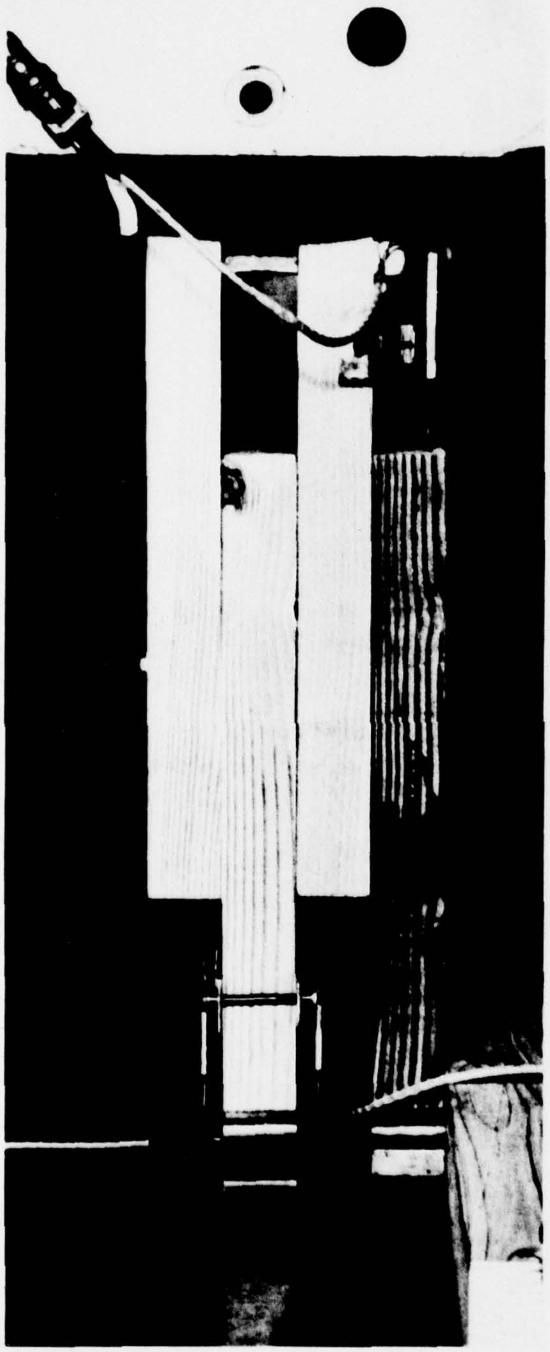

Figure 4.—Testing of four-member joints showing position of transducers.
(M 144 227)

600-K-2. If side members are thicker than one-half the thickness of the main member, no increase in tabulated loads is permissible.
600-K-3. When the side members are less than one-half the thickness of the main member, the tabulated loads indicated for a main member which is twice the thickness of thinnest side members used shall apply. For example, with 2-inch side members and a 10-inch center member, the tabulated loads for a 4-inch center member shall be used.

The effect of various ratios of side member to main member thickness on the joint proportional limit load is graphed in figure 6. Proportional limit load, the joint property on which design values are based, is used for comparing joint types. There is a fairly uniform rise in proportional limit load with increasing side member thickness when the center member thickness remains constant. The one exception was the joints with 1/2-inch bolts and 3-inch side members. Load-deformation curves for these joints were not of typical shape and thus proportional limit loads may be in error.

A comparison of proportional limit loads with present design recommendations (fig. 6) shows that the present design practice handles very adequately the effect of side member thickness.

Two-member joints.—Design procedures presently recommended for two-member joints appear in NDS[3/] as follows:

600-L-2. When a joint consists of two members (single shear) of equal thickness, one-half the tabulated load for a piece twice the thickness of one of the members shall apply.
600-L-3. When members of a two-member joint are of unequal thickness, one-half the tabulated load for a piece twice the thickness of the thinner member shall apply.

However, Trayer's report[2/] seems to contradict the NDS[3/] recommendation for design of two-member joints: "Tests have shown that a load applied to only one end of a bolt, perpendicular to its axis, may safely be taken as half the symmetrical two-end load for the same value of L/D."

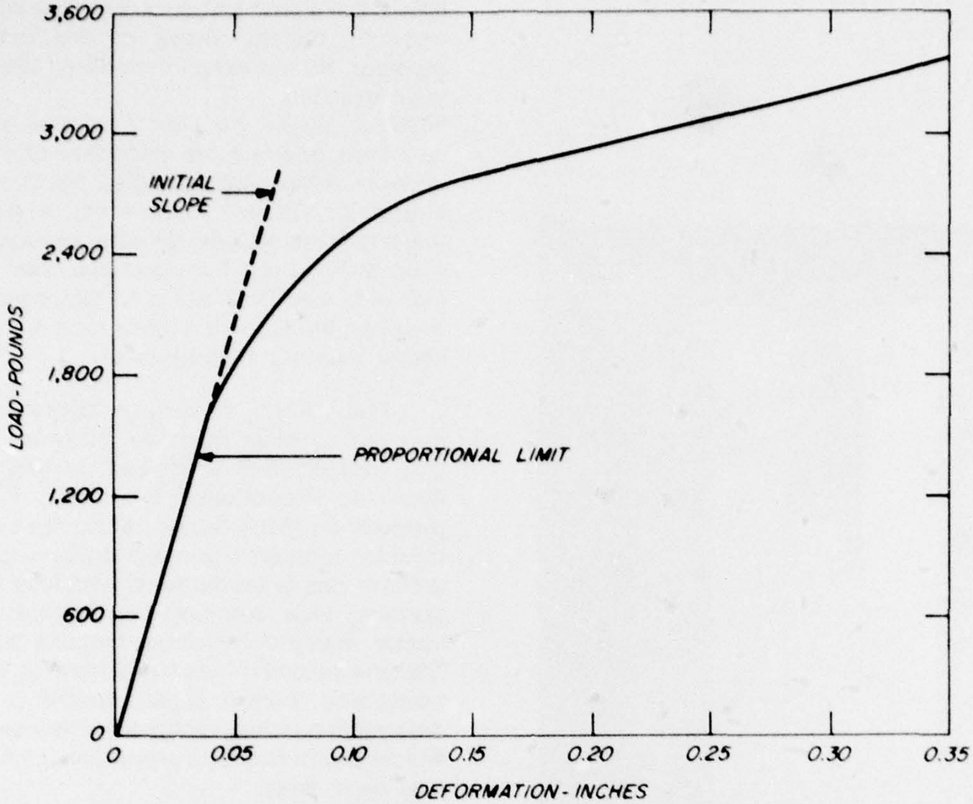

Figure 5.—Typical load-deformation curve for three-member bolted joint (3/8-in. bolt, 2-in. center member, and 3-in. side members). (M144 964)

Table 2.—Proportional limit loads for two-member bolted joint compared to two different three-member joints

Bolt diameter	Two-member joints		Three-member joints			Ratio of two-member to three-member proportional limit load
	Member thicknesses	Proportional limit load	Member thickness		Proportional limit load	
			Side	Main		
In.	In.	Lb	In.	In.	Lb	
1/2	1-1/2 and 1-1/2	840	1-1/2	3	2,320	[1]0.36
3/4	1-1/2 and 1-1/2	1,170	1-1/2	3	4,220	[1].28
1/2	1-1/2 and 1-1/2	840	3/4	1-1/2	1,930	[2].44
3/4	1-1/2 and 1-1/2	1,170	3/4	1-1/2	2,060	[2].57
1/2	3 and 1-1/2	960	1-1/2	3	2,320	[1].41
3/4	3 and 1-1/2	1,770	1-1/2	3	4,220	[1].42
1/2	3 and 1-1/2	960	3/4	1-1/2	1,930	[2].50
3/4	3 and 1/2	1 770	3/4	1-1/2	2,060	[2].86

[1] Comparison complying with procedurees in NDS.[3]
[2] Comparison complying with statement in Trayer.[2]

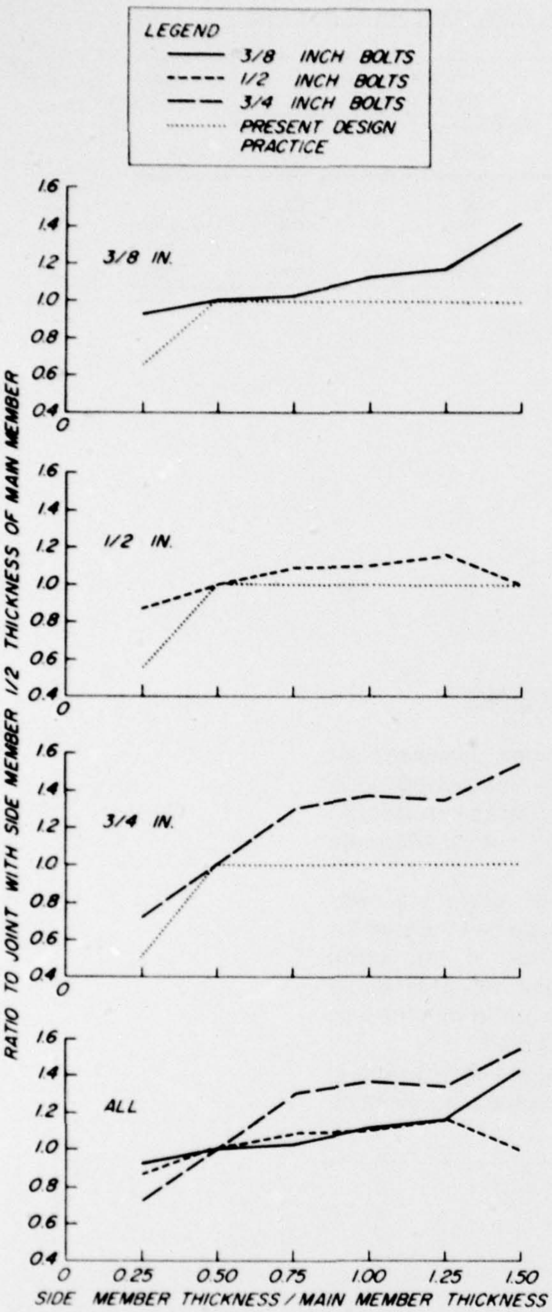

Figure 6.—Proportional limit load versus side member thickness for three-member joints. Center member thickness was 2 inches for all joints plotted.
(M 144 962)

Proportional limit loads for two-member joints which comply with the Trayer[2/] and NDS[3/] statements are compared to those for three-member joints in table 2. The procedures recommended by NDS[3/] do not appear to be adequate because the ratio of loads for two-member to three-member joints with main member twice the thickness of the thinnest member are well below 50 percent. The procedure described by Trayer[2/] appears to be adequate for handling two-member joints, because the ratios are all near or above 50 percent.

Four-member joints.—Design procedure presently recommended for multiple-member joints is in NDS[3/] as follows:

600-L-4. For multiple-member joints other than two or three members, of which the pieces are of equal thickness, the allowable load shall vary as the number of shear planes involved; the allowable load for each shear plane shall be equal to one-half the tabulated load for a piece the thickness of the member involved. Thus, when a joint consists of four members of equal thickness, one and one-half times the tabulated load for a piece the thickness of one of the members shall apply.

Separate measurements of joint deformation on each shear plane showed no significant difference, and thus to base design on a uniform value for each shear plane would seem to be in line with experimentally determined values.

Three- and four-member joints are compared on the basis of load per shear plane (table 3). It appears from this comparison that the present recommendation for design of four-member joints is more than adequate.

Table 3.—Comparison of three- and four-member bolted joints on the basis of load per shear plane

Bolt diameter	Proportional limit loads		Proportional limit loads divided by shear planes		Ratio
	Three-member [1] joints	Four-member [2] joints	Three-member [1] joints	Four-member [2] joints	
In.	Lb	Lb	Lb	Lb	
3/8	1,130	2,500	560	830	1.48
1/2	1,960	3,640	980	1,210	1.23
3/4	3,010	5,980	1,500	1,990	1.33

[1] Three-member joints had 2-in. main member and 1-in. side members.
[2] Four-member joints had all members 2-in. thick.

CONCLUSIONS

The proportional limit load increases for three-member joints with increasing side member thickness. The present design procedure as given in NDS seems adequate for handling this situation.

The proper way of designing two-member joints would be to use half the load for a joint with main member of the same thickness as the thinner member. This would bring the design procedure in line with the way four-member joints are handled.

The present procedure for designing joints of four or more members as given in NDS is adequate.

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